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Effect of Discontinuities and Uncertainties on the Response and Failure of Composite Structures

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Attention:

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Abstract

The overall goal of this research was to assess the effect of discontinuities and uncertainties on the nonlinear response and failure of composite structures subjected to combined mechanical and thermal loads. The four key elements of the study were: a) development of simple and efficient procedures for the accurate determination of transverse shear and transverse normal stresses in structural sandwiches as well as in unstiffened and stiffened composite panels and shells; b) study the effects of transverse stresses on the response, damage initiation and propagation in composite and sandwich structures; c) use of hierarchical sensitivity coefficients to identify the major parameters that affect the response and damage in each of the different levels in the hierarchy (micro-mechanical, layer, panel, subcomponent and component levels); and d) application of fuzzy set techniques to identify the range and variation of possible responses. The computational models developed were used in conjunction with experiments, to understand the physical phenomena associated with the nonlinear response and failure of composite and sandwich structures. A toolkit was developed for use in conjunction with deterministic analysis programs to help the designer in assessing the effect of uncertainties in the different computational model parameters on the variability of the response quantities.

The Principal Investigator was Dr. Ahmed K. Noor, Ferman W. Perry Professor of Aerospace Structures and Applied Mechanics, and the NASA Technical Officer was Dr. James H. Starnes, Jr., Head, Senior Engineer, Structures and Materials Competency, NASA Langley Research Center.

Summary of Accomplishments

During the period Feb. 1, 1998 to Dec. 31, 2000, the research was focused on: a) accurate determination of transverse normal stresses in composite and sandwich panels; b) study of the thermo-mechanical response of curved sandwich and composite panels subjected to combined pressure loading, edge displacement and temperature gradient through the thickness; c) study of the effect of cutouts on the response of curved unstiffened composite and sandwich panels; and d) application of fuzzy set techniques to identify the range and variation of possible responses of composite panels.

The analysis on curved sandwich and composite panels was based on a first-order shear-deformation Sanders-Budiansky type theory with the effects of large displacements, moderate rotations, average transverse shear deformation through-the-thickness, and laminated anisotropic material behavior included. A linear Duhamel-Neuman type constitutive model was used and the material properties were assumed to be independent of temperature.

The results of this research are contained in seven papers. Two technical presentations were made. The lists of presentations and publications (along with the abstracts of the publications) are given subsequently.

Presentations

Noor, A. K., "Uncertainty Analysis of Composite Structures," 40th AIAA/ASME/ASCE/ASC Structures, Structural Dynamics and Materials Conference, April 12-15, 1999, St. Louis, MO;

also presented at the European Conference on Computational Mechanics (ECCM'99), Aug. 31-Sept. 3, 1999, Munich, Germany.

Publications

Evaluation of Transverse Thermal Stresses in Composite Plates Based on First-Order Shear Deformation Theory
Raimund Rolfes, Ahmed K. Noor and H. Sparr
Computer Methods in Applied Mechanics and Engineering, Vol. 167, Nos. 3-4, Dec. 1998, pp. 355-368

A post-processing procedure is presented for the evaluation of the transverse thermal stresses in laminated plates. The analytical formulation is based on the first-order shear deformation theory and the plate is discretized by using a single-field displacement finite element model. The procedure is based on neglecting the derivatives of the in-plane forces and the twisting moments, as well as the mixed derivatives of the bending moments, with respect to the in-plane coordinates. The calculated transverse shear stiffnesses reflect the actual stacking sequence of the composite plate. The distributions of the transverse stresses through-the-thickness are evaluated by using only the transverse shear forces and the thermal effects resulting from the finite element analysis. The procedure is implemented into a post-processing routine that can be easily incorporated into existing commercial finite element codes. Numerical results are presented for four- and ten-layer cross-ply laminates subjected to mechanical and thermal loads.

Analysis of Composite Panels Subjected to Thermo-mechanical Loads
Ahmed K. Noor and Jeanne M. Peters
Journal of Aerospace Engineering, ASCE, Vol. 12, No. 1, Jan. 1999, pp. 1-7.

The results of a detailed study of the effect of the cutout on the nonlinear response of curved unstiffened panels are presented. The panels are subjected to combined temperature gradient through-the-thickness combined with pressure loading and edge shortening or edge shear. The analysis is based on a first-order shear-deformation Sanders-Budiansky type shell theory with the effects of large displacements, moderate rotations, transverse shear deformation and laminated anisotropic material behavior included. A mixed formulation is used with the fundamental unknowns consisting of the generalized displacements and the stress resultants of the panel. The nonlinear displacements, strain energy, principal strains, transverse shear stresses, transverse shear strain energy density, and their hierarchical sensitivity coefficients are evaluated. The hierarchical sensitivity coefficients measure the sensitivity of the nonlinear response to variations in the panel parameters, as well as in the material properties of the individual layers. Numerical results are presented for cylindrical panels and show the effects of variations in the loading and the size of the cutout on the global and local response quantities and their sensitivity to changes in the various panel, layer and micro-mechanical parameters.

Structures Technology for Future Aerospace Systems
Ahmed K. Noor, Samuel L. Venneri, Donald B. Paul and M. A. Hopkins
Computers and Structures, Vol. 74, No. 5, Jan. 2000, pp. 507-519

Structures technology encompasses a wide range of component technologies from materials development to analysis, design, testing, production, and maintenance. Materials and structures have been largely responsible for major performance improvements in many aerospace systems. The maturation of computational structures technology and the development of advanced composite materials, witnessed during the past thirty years, have improved structural performance, reduced operational risk, and shortened development time. The design of future aerospace systems must meet additional demanding challenges. For aircraft, these include affordability, safety, and environmental compatibility. For military aircraft, there is a shift in thrust from best performance to lowest cost for good performance. For space systems, new challenges are a result of a shift in strategy from long-term, complex, and expensive missions to those that are small, inexpensive, and fast.

Materials and structures, in addition to being enabling technologies for future aeronautical and space systems, continue to be key elements in determining the reliability, performance, testability, and cost effectiveness of these systems. The treatment of future directions in structures technology in a single article must necessarily be selective and brief. The focus of the present article is on developments in component technologies that will improve the vehicle performance, advance the technology exploitation process, and reduce system life-cycle costs. The component technologies are grouped in seven categories, namely: smart materials and structures; multi-functional materials and structures; affordable composite structures; extreme environment structures; flexible load-bearing structures; and computational methods and simulation-based design. The development of each of the component technologies is a multidisciplinary activity, which involves tasks in other disciplines. In this article, the trends in each of the component technologies are discussed and the applicability of these technologies to future vehicles is described.

Uncertainty Analysis of Composite Structures
Ahmed K. Noor, James H. Starnes, Jr. and Jeanne M. Peters
In *Recent Advances and Future Trends in Composite Materials and Structures*, special issue of *Computer Methods in Applied Mechanics and Engineering*, Vol. 185, Nos. 2-4, May 2000, pp. 413-432; also, in Proc. of AIAA/ASME/ASCE/AHS/ ASC 40th Structures, Structural Dynamics and Materials Conf., April 12-15, 1999, St. Louis, MO, 1999, pp. 2905-2926.

A two-phase approach and a computational procedure are presented for predicting the variability in the nonlinear response of composite structures associated with variations in the geometric and material parameters of the structure. In the first phase, hierarchical sensitivity analysis is used to identify the major parameters, which have the most effect on the response quantities of interest. In the second phase, the major parameters are taken to be fuzzy parameters, and a fuzzy set analysis is used to determine the range of variation of the response, associated with preselected variations in the major parameters. The effectiveness of the procedure is demonstrated by means of a numerical example of a cylindrical panel with four T-shaped stiffeners and a circular cutout.

Accurate Determination of Transverse Normal Stresses in Sandwich Panels Subjected to Thermomechanical Loadings

Ahmed K. Noor and Moinuddin Malik

Computer Methods in Applied Mechanics and Engineering, Vol. 178, 1999, pp. 431-443.

A two-stage computational procedure is presented for the accurate determination of transverse normal stresses in sandwich panels subjected to thermomechanical loadings. The procedure involves the use of first-order shear deformation model in the first stage, and an iterational process for successive improvement of the accuracy of the displacement and stress fields in the second stage. The effectiveness of the procedure is demonstrated by means of numerical studies of thin and moderately thick flat rectangular sandwich panels. Two sets of boundary conditions are considered, namely, one with all edges simply supported, and the other with two opposite edges simply supported and the remaining two clamped. The displacement components and the transverse shear and normal stresses obtained by the proposed computational procedure are found to be in close agreement with the solutions of the three-dimensional continuum models.

An Assessment of Five Modeling Approaches for Thermo-mechanical Stress Analysis of Laminated Composite Panels

Ahmed K. Noor and Moinuddin Malik

Computational Mechanics, Vol. 25, No. 1, Feb. 2000, pp. 43-58

A study is made of the effects of variation in the lamination and geometric parameters, and boundary conditions of multi-layered composite panels on the accuracy of the detailed response characteristics obtained by five different modeling approaches. The modeling approaches considered include four two-dimensional models, each with five parameters to characterize the deformation in the thickness direction, and a predictor-corrector approach with twelve displacement parameters. The two-dimensional models are first-order shear deformation theory, third-order theory; a theory based on trigonometric variation of the transverse shear stresses through the thickness, and a discrete layer theory. The combination of the following four key elements distinguishes the present study from previous studies reported in the literature: a) the standard of comparison is taken to be the solutions obtained by using three-dimensional continuum models for each of the individual layers; 2) both mechanical and thermal loadings are considered; 3) boundary conditions other than simply supported edges are considered; and 4) quantities compared include detailed through-the-thickness distributions of transverse shear and transverse normal stresses.

Based on the numerical studies conducted, the predictor-corrector approach appears to be the most effective technique for obtaining accurate transverse stresses, and for thermal loading, none of the two-dimensional models is adequate for calculating transverse normal stresses, even when used in conjunction with three-dimensional equilibrium equations.

Uncertainty Analysis of Stiffened Composite Panels
Ahmed K. Noor, James H. Starnes, Jr. and Jeanne M. Peters
Composite Structures (Special Issue Honoring the 70th Birthdays of Charles Bert and Jack R. Vinson), Vol. 51, No. 2, Feb. 2001 (to appear).

A study is made of the variability in the nonlinear response of three stiffened composite panels associated with variations in their geometric and material parameters. The three panels have a cylindrical skin with either four or five T-shaped stiffeners. Two of the panels have a notch and the third panel has a circular cutout. Hierarchical sensitivity analysis is used to identify the major parameters at the micro-mechanical, layer, laminate and sub-component levels. The major parameters are then taken to be fuzzy parameters, and a fuzzy set analysis is used to determine the range of variation of the response associated with pre-selected variations in the major parameters.